The Spring 2000 Cloud IOP
Science and Experiment Planning Document

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Executive Summary

Diagnostic quantities related to the three dimensional distribution of cloudiness continue to be difficult to determine using the observational paradigm of the ARM program. ARM's detailed sensing of clouds occurs in a vertical column at a single geographical locale at each clouds and radiation testbed (CART) site. However, knowledge of the cloud field properties are still needed to address many important scientific questions including the coupling between the cloud field and the radiative heating profile and the cloud field and the advective tendencies of condensate. With the existing operational instrumentation at the ARM sites, scientific questions related to the volumetric distribution of clouds can be treated only approximately through various assumptions built into algorithms. Our primary goal in this IOP is to generate a dataset that can be used to evaluate these assumptions and quantify the uncertainty of the algorithms into which these assumptions are codified.

The Spring 2000 cloud IOP will occur around a cluster of millimeter cloud radars, lidars and passive instruments distributed in a triangular array with vertices near the southern great plains (SGP) central facility (CF) Blackwell Tonkawa airport (~20km) and a supplemental facility ~15 km east of the SGP CF. Within this array we will deploy aircraft to collect in situ microphysical data and an airborne remote sensor platform that will collect millimeter radar data and upwelling and downwelling solar fluxes. Additionally, coordination with the NASA ER2 and with spaceborne sensors will be attempted. Data collection will concentrate on cloud situations that can be adequately treated using the deployed observational assets and include primarily thin, nonprecipitating, single-layered cloud fields associated with synoptic or mesoscale disturbances. In this document we provide some detail on the experimental objectives, deployment of instrumentation, basic design of experiments, and an implementation plan.

1. Introduction:

The motivation for the conceptual design of this experiment arises from three basic observations concerning the present state of the cloud-climate radiation problem and ARM's relationship to it:

- The ARM program is largely designed around the single column modeling concept (Stokes and Schwartz, 1994). Thus, the southern great plains (SGP) CART site approximates a general circulation model (GCM) grid box of approximately 250 km x 250 km even though detailed surface-based cloud remote sensing occurs only near the center of this box at the SGP central facility (CF). It is not clear under what circumstances and to what degree of accuracy the CF cloud observations can be used to approximate the cloud field properties in the large area represented by the CART site. In order to address this issue from an observational perspective, we will deploy surface-based and airborne instrumentation within the CART domain to map the field of cloudiness under various conditions. Given unlimited resources, an ideal experimental design to map the cloud field adequately would be to deploy active remotes sensors in a regular grid within the CART at spacings of a few kilometers. Our request for construction of 6,250 millimeter radars was denied by the current ARM administration. We were forced to choose between deploying the existing fleet of cloud radars (consisting of 5 research grade instruments) evenly within the CART or concentrating them near the CF where the cloud field could be resolved at something close to the scale of the cloud elements. The latter option was chosen since the former option would not address the fundamental question of how isolated observations can be converted into cloud field information. Since numerical weather prediction (NWP) models are emerging as a testbed within which cloud parameterizations for GCMs can be evaluated (Mace et al., 1998), the detailed cloud field information that we will collect over a small area can be scaled appropriately to apply to GCM grid box/CART scales.
- Since certain physical processes cannot be observed and/or validated experimentally, numerical models that resolve the dynamical and microphysical processes of clouds (Starr and Cox, 1985) have been adopted as an intermediate step between climate models and observations (Randall et al, 1996). These so-called cloud resolving models typically have grid spacing of 100's of meters and domain sizes of 10's of kilometers and range in complexity from models with highly detailed dynamics and parameterized physics to those with rudimentary dynamics and highly detailed physics. Thus, a CRM grid often represents a few grid points of a global model. Validation of the process occurring within these CRM's is difficult and has only been accomplished in a cursory manner. However, the results from these models are being used to develop parameterizations for GCMs. We will collect data sufficient to validate CRMs.
- The impact of nonisotropy and horizontal inhomogenity of the cloud field on the radiative heating has remained difficult to assess due to a lack of appropriate observational data.

The primary objective of the Spring 2000 Cloud IOP arise from the above three points and can be expressed as follows.

Generate a dataset suitable for the determination of the three dimensional distribution of cloudiness and cloud properties within the experimental domain. From this data set,

1. Quantify the ability of algorithms to estimate the three dimensional properties of the cloud field at various spatial and temporal scales using data from operational ARM instruments.
2. Conduct process studies in collaboration with CRM models to investigate the relationship between the dynamical setting and the micro- and macrophysical cloud properties that evolve within and advect through the experimental domain. Evaluate the utility of using CRM results to develop larger scale parameterizations.
3. Examine the relationship(s) between the volumetric distributions of cloud microphysical properties and the transfer of radiation through the cloudy atmosphere.

Secondary objectives of the Cloud IOP include:

- Provide support in the form of cloud microphysical information to the ARESE II effort.
- Validation of cloud properties derived from platforms on board the Terra spacecraft.
- Expand the database of cases for validation of cloud property retrieval algorithms being developed for ground based remote sensors.

2. Experimental Resources:

The spring 2000 Cloud IOP will be held near the Southern Great Plains (SGP) central facility (CF) from 1-21 March 2000. This period will coincide with the ARESE II field program and a deployment of the NASA ER2 aircraft in support of EOS objectives. Given the experimental objectives outlined above, this timeframe is optimal to 1) avoid the period of most active deep convection in this region, 2) have a reasonable probability of encountering liquid phase boundary layer clouds in air cold enough not to support substantial insect life, and 3) scheduling pressures from the various participants.

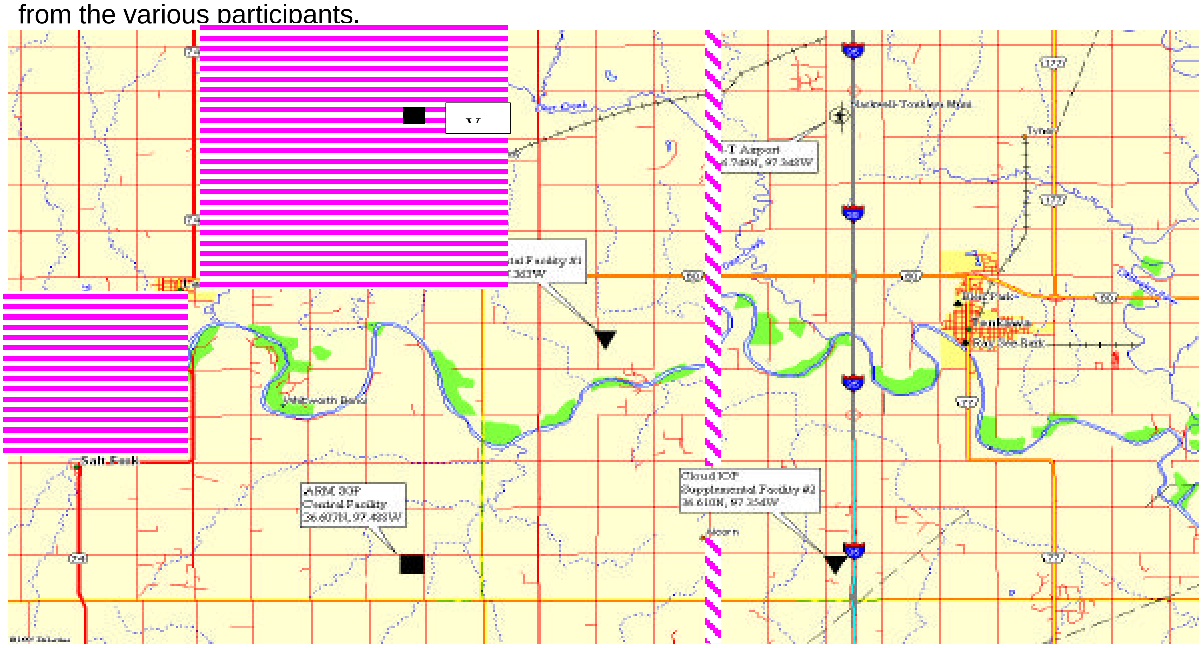

Figure 1. The location of the principal data collection facilities for the Spring 2000 Cloud IOP. Refer to Tables 1-3 and the text for additional information. The heavy purple line is the location of the Vance Air Force Base Military Operating Area (MOA). The site VF1 (Virtual Facility) is marked solely for reference and will have no instruments deployed on the ground.

In addition to the normal compliment of instrumentation at the ARM SGP site, an extensive array of visiting surface-based, airborne and space-based instrumentation will be deployed in support of this IOP. In order to address the primary objective of the IOP, ARM has established three temporary sites. The Blackwell Tonkawa (BT) airport will form the northeast vertex of an approximate grid square shown in Figure 1. Another site will exist midway along the diagonal from BT to the CF and is designated (SF1). The third supplemental site will be situated due east of the CF and is designated (SF2). For reference purposes, an uninstrumented waypoint designated VF1 (virtual facility) is marked on Figure 1 in the northwest corner of the experimental area. Table 1 gives the locations of the various sites and distances between them. Tables 2 and 3 list the various instruments, associated data streams and the principal investigator(s) responsible for each instrument. Table 4 lists the visiting instruments that will be stationed at the CF. In addition to these visiting instruments at the CF, certain instruments such as the millimeter cloud radar (MMCR) may be run in other than normal modes during the IOP. For instance, the MMCR will likely collect full Doppler Spectra during most of the intensive data collection periods. The primary airborne assets for the cloud IOP will be the University of North Dakota (UND) Cessna Citation (PI: Mike Poellot, UND). The Citation will be the primary in situ platform for the cloud IOP and will carry the instrument payload listed in Table 5. The UND Citation is funded for nominally 30 research hours during the IOP. The Spec Lear (PI: Paul Lawson, Spec Inc.) will participate as an in situ platform when needed to supplement or compliment the Citation. The Lear payload is listed in Table 6. The Twin Otter is being deployed as an ARESE II airborne platform and will carry a full compliment of radiometric instrumentation as documented in the ARESE II science plan (Ellingson and Tooman, Editors). In addition to the radiometry, the Twin Otter will also carry the JPL/Umass Airborne Cloud Radar (ACR) and will provide support for the cloud IOP during non-ARESE cloud days. Due to the obvious synergy between ARESE II and the Cloud IOP, ARESE II will alter their normal flight patterns on days of interest to them and overfly the cloud radar systems deployed for the Cloud IOP. The ER2 will be deployed to Madison, WI from late February – 11 March to gather validation data in support of the MODIS instrument on board the Terra satellite (PI: Chris Moeller, CIMSS - Univ. of Wisconsin). As part of this deployment, approximately 3-4 flights over the SGP site are planned to take place in collaboration with the Cloud IOP. The instrument compliment on board the ER2 is listed in Table 7. Obviously, the cloud IOP will endeavor to take advantage of this significant asset and careful coordination between the missions will be maintained.

Table 1. Physical location of the data collection facilities and distances in kilometers between them. CF refers to the SGP Central facility, SF1 to Supplemental Facility 1, SF2 to Supplemental Facility 2, BT to the Blackwell Tonkawa airport, and VF1 to Virtual Facility 1 where no instruments will be located but will serve as a reference point for certain experiments.

Site, lat/lon	CF	SF1	SF2	BT	VF1
CF 36.607/97.488	0	9.5	12.0	20.1	16.0
SF1 36.677/97.425		0	7.8	10.5	9.8
SF2 36.610/97.354			0	15.5	19.5
BT 36.749/97.348				0	12.5
VF1 36.749/97.488					0

Table 2. Supplemental Facility #1 &2 instrument list			
Instrument	**Data Stream(s)**	**Data Product(s)**	**Responsible Scientist**
94 GHz Radar (Vertically Pointing)	Radar Reflectivity, Doppler Velocity, Spectral width, Doppler Spectra	Cloud Mask, water content, particle size, Turbulence	Bruce Albrecht, University of Miami (SF1) Eugene Clothiaux, Penn State (SF2)
Total Sky Imager (TSI)	Graphical images of the celestial dome	Cloud fractional coverage	Chuck Long, Penn State
Rotating Shadow Band Radiometer (RSR)	Diffuse and Total solar radiation	Direct Solar radiation, sky fractional coverage	Chuck Long, Penn State
Vaisala Ceilometer	Laser backscatter	Cloud Base to 25 kft	Connor Flynn, PNL
MFRSR	Diffuse and total narrow band solar irradiance	Aerosol and cirrus optical depth	Schmelzer (?), Baranard, PNNL
Microwave Radiometer (MWR)	23 and 31 GHz Brightness Temperatures	Water liquid and vapor paths	Jim Liljegren, ANL
Temp/RH	Surface Temperature and Moisture	Lifting Condensation Level	Scott Richardson, Oklahoma Univ.

Table 3. Instruments at the Blackwell Tonkawa Airport			
Instrument	**Data Stream(s)**	**Data Product(s)**	**Responsible Scientist**
35/95 GHz Scanning Radar	Radar Reflectivity, Doppler Velocity, Spectral width, Doppler Spectra	Cloud Mask, water content, particle size, Turbulence	Steve Sekelsky, Univ. Of Mass.
Total Sky Imager (TSI)	Graphical images of the celestial dome	Cloud fractional coverage	Chuck Long, Penn State
Rotating Shadow Band Radiometer (RSR)	Diffuse and Total solar radiation	Direct Solar radiation, sky fractional coverage	Chuck Long, Penn State
Micropulse Lidar	Laser backscatter	Cloud Base to Tropopause	Dave Turner, PNNL
MFRSR	Diffuse and total narrow band solar irradiance	Aerosol and cirrus optical depth	Jim Baranard, PNNL
Profiling Microwave Radiometer	Brightness Temperatures at multiple microwave channels	Profiles of temperature, cloud liquid and water vapor	Fred Solheim, Radiometrics Corp.
Whole Sky Imager	Narrowband Visible radiance images	Cloud fractional coverage, Narrow band radiance, cloud optical characteristics,	Tim Tooman, Sandia National Lab.
Temp/RH	Surface Temperature and Moisture	Lifting Condensation Level	Scott Richardson, Oklahoma Univ.

Table 4. Supplemental Instruments at the SGP CF			
Instrument	Data Stream(s)	Data Products	Responsible Scientist
33 GHz Scanning Radar	Radar Reflectivity, Doppler Moments	Cloud Mask, Cloud microphysical properties	Brooks Martner, NOAA ETL
PRT-5	NFOV Mid-IR Radiance	Cloud emissivity	Brooks Martener, NOAA ETL

Table 5. UND Citation Instruments (Principal Contact: Mike Poellot, Univ. of North Dakota)	
Instrument	**Measurement**
Forward Scatter Spectrometer Probe (FSSP)	Size distribution (2-47 μm)
PMS 1DC	Size distribution (20-600 μm)
PMS 2DC	Size Distribution (60-1500 μm)
PMS 2DP (questionable)	Size distribution (200-2000 μm ?)
Cloud Particle Imager (CPI)	Holographic particle images, habit, size distribution (20-2500 μm ?)
Counterflow Virtual Impacter (CVI)	Ice Water Content
King Probe	Liquid water content
Rosemount Icing Meter	Liquid water content
Scintrix Chemiluminescent	Ozone concentration
State Parameters	Turbulence
TSI Alcohol Condensing	Condensation Nuclei counter
Frost Point Hygrometer	Water vapor concentration

Table 6. Spec Inc. Lear (Principal Contact: Paul Lawson, Spec Inc.)	
Instrument	**Measurement**
Forward Scatter Spectrometer Probe (FSSP)	Size distribution (2-47 μm)
PMS 2DC	Size Distribution (60-1500 μm)
Cloud Particle Imager (CPI)	Holographic particle images, habit, size distribution (20-2500 μm ?)
State Parameters	

Table 7. ER2 Instruments (Principal Contact: Chris Moeller, Univ. of Wisconsin)	
Instrument	**Measurement**
Scanning HIS	high spectral resolution IR radiance
Cloud Lidar System (CLS)	Lidar Backscatter – nadir
Visible Imaging System (VIS)	Video image of ground track
AirMISR	
MODIS Airborne Simulator (MAS)	Narrow band radiance from visible to far IR - Imager
RC-10 Camera	5-10 m resolution photography

3. Data Policy: Products, Analysis and Calibration:

Radiometric calibration is important to many of the goals of the Cloud IOP and is being adequately dealt with by the ARESEII science team. Calibration of the millimeter radars is critical to the success of the Cloud IOP. All radars participating in the IOP have predetermined and validated calibration procedures. However, hard fought experience has taught that careful attention to this detail will avoid substantial problems in the analysis phase of this project.

Optimally, all radars would operate in close proximity to all others and calibrate against a single corner reflector. This is not a practical option. At least one radar system (the Umass CPRS) will field a corner reflector and calibrate against this standard as needed. During appropriate meteorological cases (light drizzle and cirrus) the ACR on board the Twin Otter will be used to transfer that calibration to the other radars. The ACR will carefully overfly each of the radar sites as many times as possible. Since the CPRS will have known reflectivity derived from a corner reflector, the ACR can be effectively used to transfer that calibration to the other radars. This calibration can then be used as a comparison of the calibrations derived for the other radars from other sources. Care will have to be taken to choose cases where the reflectivity is derived primarily from particles small enough to be within the Raleigh scattering approximation of the 3mm-wavelength radars and attenuation by liquid water can be neglected.

After the completion of the field phase of this IOP and after all instrument PI's have had the opportunity to generate calibrated and cloud masked data sets, the data sets will be delivered to a central archive (to be announced) so that all members of the science team may have access to them. Initial delivery of all data should occur by **1 July 2000**. As is customary for data sets like this, access will be proprietary to the individuals participating in the Cloud IOP for 6 months after the data submission deadline. The Cloud IOP data will be scheduled to enter the public domain on **1 January 2001**.

Following submission of the masked and calibrated data sets, analysis will concentrate on generating integrated products consistent with the primary objectives identified above. Since an array of cloud sensing instruments such as this has never been deployed for this purpose, a detailed description of the analysis technique(s) will certainly evolve with time and is beyond the scope of this document. However, the baseline products will include

- <u>Three dimensional cloud mask as a function of time within the study volume</u>. This product will be created by combining the time series of vertically pointing active remote sensors, with the volumetric information from the scanning systems. Data from the ACR will be used to correlate the time series data with that from the scans, as well as provide additional information on the evolution of the cloud elements as they pass through the instrumental array. Data from the sky imagers at the various locations will be used as validation. The temporal and vertical resolution of this product depends, to some extent on the characteristics of the meteorological situation and will be evaluated on a case by case basis.
- <u>Three-dimensional distribution of cloud water content and mean particle size as a function of time within the study volume</u>. This product will be challenging to arrive at accurately but should be within reach for appropriate cloud situations given careful analysis. One approach would be to apply accepted algorithms to data acquired from the vertically pointing radar systems (Matrosov et al., 1994; Mace et al., 1998; Sassen et. al., 1999, Dong et al., 1998) and then use data from the scanning and airborne systems to distribute those microphysics within the volume. In this situation, the in situ data would be used as validation. Another approach would be to apply the analysis technique introduced by Heymsfield and Palmer (1986) and Plank et al. (1980) where the aircraft and radar reflectivity data are combined, in essence, to derive intelligent regression coefficients that will enable the straightforward conversion of the radar reflectivity to microphysical properties. In practice, these methods will likely be combined to generate a hybrid product. Use can also be made of the sophisticated radiometric instrumentation aboard the Twin Otter to develop new approaches to the retrieval of microphysical properties using combined passive and active remote sensing data.
- <u>Three-dimensional distribution of radiative heating rates</u>. Since the Twin Otter payload will include a suite of highly accurate flux radiometers, the microphysical data derived from the remote sensors can be used to asses the deposition of radiant flux within the cloud layer. The accuracy of this product will be significantly enhanced by coordination with the ER2 and/or the Terra satellite.
- <u>Process studies</u> will be conducted as appropriate. Of particular interest is how cloud systems are coupled to the meteorological conditions and how this relates to the evolution of the cloud properties that are observed.

4. Observational Objectives and Experiment Implementation Strategy:

In order to meet the primary and secondary objectives of the IOP, the cloud fields of most interest will tend to be characterized by

- Relative uniformity in aerial coverage over the instrumental array,
- Layered characteristics; the vertical extent of the cloud field should be much less than the characteristic horizontal dimension of the instrument array.
- General isolation from other cloud layers
- A single phase.
- Of sufficient radar reflectivity to be reasonably sensed by the vertically pointing radars

These cloud types include

1. fields of broken to overcast cirrus associated with synoptic disturbances (frontal overrunning and jet streams) or anvil cirrus reasonably removed from their convective source,
2. fields of overcast liquid-phase stratocumulus either sufficiently removed from the ground for insects not to be a problem or in air cold enough to suppress insect activity near the boundary layer clouds but warm enough for the clouds to remain primarily liquid phase,
3. Two-layer situations of stratus or cirrus with layers sufficiently separated to safely deploy two in situ aircraft simultaneously or situations of stratus and cirrus occurring together.

Other cloud situations of lesser priority but still of general interest include

4. Fields of glaciating altostratus or altocumulus characterized by a thin supercooled liquid layer and a deeper ice precipitation layer.
5. Isolated cirrus generating cells
6. Fields of scattered to broken cumulus.

- The UND Cessna Citation will be the primary in situ platform for this IOP and the Spec Lear will be utilized as appropriate. The use of both in situ aircraft will be dictated when,
    1. Two well-separated cloud layers of interest are expected,
    2. Crew rest requirements for the Citation personnel cause the Citation to be grounded,
    3. Mechanical or instrument problems with the Citation make the Lear a more viable scientific platform.
- Missions will generally be conducted during the daylight hours. Situations that will cause a deviation from this general rule include,
    1. coordination with the ER2 who may conduct missions in support of the 10:30 PM Terra overpass,
    2. to meet objectives. Obviously, a cloud experiment is at the mercy of the cloud conditions. If conditions are good, night missions will not be required. If conditions are poor, we will need to take advantage of any opportunities that might arise.

In the following, we outline the basic design of three experiments. While the meteorological situation and logistical considerations (commercial traffic, operational instruments, etc) will likely dictate real-time modifications to these plans, they are meant to serve as a basic outline from which mission planning during the IOP can proceed.

Experiment 1 - Cloud Types 1, 2, 4 and 5:

- Purpose: Map the occurrence and evolution of the microphysical and radiative characteristics of the cloud field within the experimental domain.

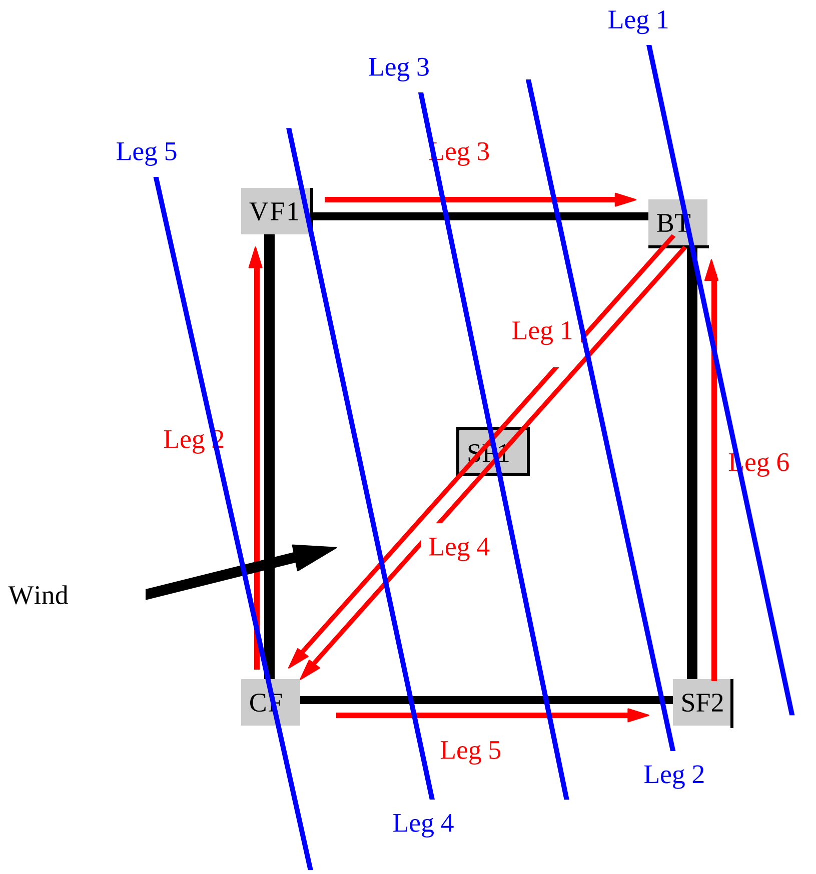

Figure 2. The blue lines show the approximate cross wind flight pattern of the twin otter for sampling cirrus. The red lines show the approximate flight pattern of the in situ aircraft.

- Critical[1] Instrumentation: Millimeter Cloud Radar (MMCR), Lidars at the CF, Scanning Radar at either the CF or Blackwell-Tonkawa, ACR, all in situ microphysical probes.
- Implementation:
  - <u>Vertically pointing radars</u>: It is important that the most accurate Doppler velocity information be acquired from the vertically pointing radars. It is, therefore, desirable that these systems collect Doppler spectra during the data collection period at the highest temporal and vertical resolution that is consistent with sensing the cloud.
  - <u>Scanning radar(s)</u>: Given the tradeoffs between sensitivity and scan speed, the experimental objectives will be better served by slower scans with higher sensitivity. When two scanning radars are operating (ETL K at the CF and Umass CPRS at the B-T airport) each radar will be responsible for their half of the experimental domain. In other words, ETL will be responsible for sweeping out the southwest half of the rectangle and Umass, the northeast half. The repeating scan sequence should consist of 1-3 minutes of fairly rapid volume-mapping sector scans followed by 3-5 minutes of slower more sensitive RHI scans along the principal flight tracks of the in situ aircraft.
  - <u>In Situ Aircraft:</u> The in situ aircraft will attempt to profile the microphysical properties of the cloud field as it advects through the experimental domain. The flight pattern will generally begin with a slow ascent (500 ft/minute) from cloud base to cloud top along the periphery of the rectangle. Once cloud top is reached the aircraft will enter a pattern that

[1] defined as an experimental asset that is required for the conduct of the mission

follows the principal diagonal and the periphery of the domain as shown in Fig 2 (in red). While not indicated in the diagram, the aircraft should maintain straight and level flight for at least 30 seconds after crossing a remote sensing facility before beginning a turn into the next leg. Upon completion of leg 6 the aircraft will attempt a 1000ft descent before beginning the next sequence of legs starting with leg 1. Upon completion of the descent through the cloud layer, the sequence will be repeated starting with a slow spiral ascent to the layer top. Sometime during each flight, an extended (50-100km) along wind leg will be attempted to gather turbulence data. The altitudes of the turbulence legs will be determined during the mission but should be near the generating region of the cirrus layer.

- Airborne Cloud Radar: The objective of the Twin Otter will be to collect ACR data to provide a spatial context in which to place the vertically pointing and scanning remote sensing radar data. A secondary objective will be the collection of radiometric data below the cloud layer. Therefore, straight and level flight along the tracks is critical. The Twin Otter will fly as close to the cirrus layer as practical to maximize sensitivity. The flight pattern will consist of racetracks (semi-minor axis of 2.5 miles, semi-major axis of 10 miles) oriented perpendicular to the main wind flow at the cloud level (Figure 2, in blue). These racetracks should begin on the downwind side of the domain and progress to the upwind side. Upon completion of a series of racetracks on the upwind side of the domain, the Twin Otter will enter the pattern followed by the in situ aircraft (Figure 2, in red) only in an opposing sense (to maximize overlap with the in situ aircraft). After completing one circuit of the periphery and principal diagonal, the racetrack pattern will be reentered and the pattern repeated.

Experiment 2 – Cloud Types 1, 3 and 5:

- Purpose: With the unique combination of ground based and airborne remote sensors available for this IOP we have an opportunity to examine the development of cirrus microphysical and radiative characteristics as they advect over the ground-based remote sensors. Our goal will be to map a cirrus field along a streamline for a period of time significant with respect to the lifetime of the cirrus elements.

  The focus of the experiment will shift from emphasis on a 3d volume to a two dimensional area along which the cirrus elements are advecting. While this experiment can be conducted in series with Experiment 1, Experiment 2 will be most effective when significant time can be devoted to it in order to develop statistics and allow a series of cloud elements to advect from one end of the domain to the other. Optimally the upper level wind direction should be along the radial from the CF to BT or from the CF to SF2 with little directional shear in the cloud layer. We will essentially attempt to construct and sample a two dimensional CRM domain (Starr and Cox, 1985).
- Critical Instrumentation: Millimeter Cloud Radar, Scanning Radar at either the CF, ACR, all in situ microphysical probes.
- Implementation:
  - Vertically pointing radars: It is important that the most accurate Doppler velocity information be acquired from the vertically pointing radars. It is, therefore, desirable that these systems collect Doppler spectra during the data collection period at the highest temporal and vertical resolution that is consistent with sensing the cloud.

- Scanning Radar(s): For this experiment it is not critical that there be a scanning radar at the BT airport. The scanning lidar and radar at the CF will perform continuous RHI sweeps along the wind. It is generally desired to repeat the scan sequence at least every 2-3 minutes depending on the wind speed. The metric being considered here is the time it takes for a cloud element to advect roughly 1/3 of the distance along the 20-30 km domain that can be sampled effectively by the scanning systems. In the situation where the wind direction is along the radial from the CF to the BT airport, the CPRS will perform similar continuous RHI sweeps along the wind at the BT airport. In order to keep track of any variability in the crosswind direction, every 15 minutes the scanning radar(s) should perform roughly 5 minutes of cross wind scans.

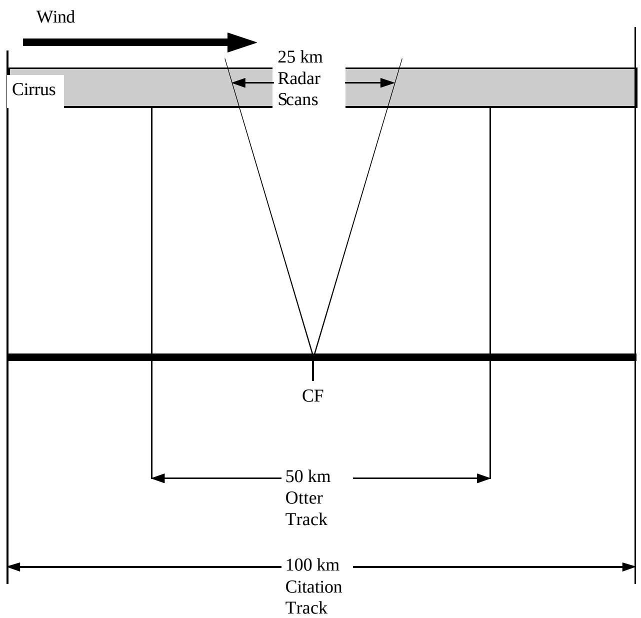

Figure 3. Schematic of the along wind experiment for Uniform cirrus. The scan pattern of the lidar is not shown here but would optimally extend as far to the horizon as practical.

- In Situ Aircraft: The UND Citation is the platform of choice for this experiment due to its capacity to measure turbulence. The in situ aircraft will initially spiral over the CF to cloud top as rapidly as possible. From a designated altitude identified by lidar and deemed to be approximately 300 m above the most likely crystal generating layer, the in situ aircraft will fly 50 km downwind, descend 300 m and proceed 100 km upwind passing over the CF halfway through the leg. Upon completing the 100 km upwind leg, the aircraft should attempt to descend 300 m and return to the point 50 km downwind of the CF, descend 300m and return. The cloud will be profiled in this manner and the sequence repeated as long a fuel and clouds permit. Each leg will take from 13-15 minutes of flight time.
- Twin Otter: Since the Twin Otter's airspeed is roughly half that of the Citation, our goal is not to coordinate the aircraft in time. However, it is desirable that the ACR make the same number of passes over a smaller fraction of the 100 km domain as made by the Citation. Given the resources on the ground at the CF, it is also important to center the ACR track on the CF. Therefore, the Twin Otter will fly 50 km along wind legs centered on the CF as close to cloud base as practical.
- Other Assets: This experiment will be particularly enhanced by coordination with the ER2 and/or Terra.

Experiment 3 – Cloud Types 2, 3, 4, and 6:

- Purpose: One of the primary reasons we (and ARESE) chose to schedule IOPs during late winter is the climatological likelihood of overcast stratocumulus conditions in air cold enough to suppress insect activity (which contaminate MMCR observations) but warm enough to allow for clouds composed of primarily of liquid water. Of the cloud conditions we have sampled in past IOP's this situation has been difficult to obtain. Sassen et al., 1999 describe such a case captured on April 30, 1994 by the UND Citation and the Umass CPRS radar. This type of cloud event is a primary goal of the cloud IOP and is also a major target of the ARESE II experiment.

Given the geographic distribution of remote sensors and the fact that the cloud system will likely exist in a northwesterly flow, we will have the opportunity to monitor a cross section of cloudy air as it advects through the CF-BT cross section. At the same time we will attempt to monitor the advective tendency of the microphysical properties within the small triangle defined by the CF, SF1 and SF2.

- Critical Instrumentation: CART MMCR, Scanning Radar at the CF, ACR, FSSP on the in situ aircraft.
- Implementation:
  - Vertically pointing radars: These systems should collect Doppler spectra at the highest temporal and vertical resolution possible. Doppler spectra will aid in understanding the relationship of the cloud to the air motions and will provide a valuable point of comparison to the in situ turbulence measurements from the Citation. If drizzle is present, Doppler spectra from these systems will help in retrieval of the drizzle mode (Babb et al., 1999) and ultimately the cloud properties.
  - Scanning Radar(s): It is important that the scanning lidar map any horizontal gradients in cloud base along the flight tracks between the CF and BT and the CF and SF2. Since there is a redundancy of radars at the CF, the scanning system at the CF (either ETL/K or CPRS) will concentrate on scanning with alternating sequences of sector scans to map the cloud characteristics in the volume defined by the small triangle and the CF-BT line. Some effort should be made to coordinate the scans along the CF-BT line when the Citation is sampling along this track. If insects are a problem the CPRS should operate primarily at 94GHz. When the CPRS system is located at the BT airport, the CPRS data collection should alternate between scans along the BT-CF line and vertical pointing data.
  - In Situ Aircraft: Given the dearth of in situ stratocumulus data available for validation of microphysical retrieval algorithms, we will attempt to maximize the coincidence of radar site crossings by the in situ aircraft. In order to accomplish this, the in situ aircraft will fly principally along the lines connecting the CF and the BT airport and the CF and SF2. These two legs will be repeated continuously and the cloud profiled by stepped level legs and slow ramped ascents and descents as appropriate. Ideally, the in situ aircraft will begin just southwest of the CF near cloud base and fly the CF-BT leg maintaining straight and level flight until passing the BT radar heading northeast. A 180^{o} turn will be executed while climbing 100-300 m toward the cloud center and the leg repeated beginning with a level pass over the BT radar. Upon reaching the CF, the pattern will be repeated except along the CF-SF2 line. After the cloud is sampled, level legs will be replaced with slow ramped ascents so that the cloud is profiled along the length of a leg. If this mission is flown during the first week of the IOP, no radar will be stationed at the BT airport and the concentration of the mission will be restricted to the CF-SF1-SF2 domain. An attempt will be made to either begin or end this type of flight with a 50-100km along-wind turbulence leg in the highest water content region of the layer on the way out and near to just above cloud top on the return.
  - Twin Otter: The focus of the Twin Otter will be collection of cloud radiation data in support of ARESE II and control of the aircraft will be maintained by the ARESE II team. According to the ARESE science plan, the aircraft will fly straight and level legs near 7 km along legs that alternate between the radar sites. As long as the radar is situated in the down-looking mode, this flight pattern will serve the purposes of the Cloud IOP.
  - Other Assets: This experiment will be particularly effective if flown in conjunction with Terra or the ER2. Comparisons of stratocumulus microphysical properties derived from ground-based and satellite-based data have shown a persistent and unexplained discrepancy in the optical depths and effective particle sizes.

5. Implementation Plan:

- Planning Coordination

The experiment PI will be responsible for maintaining close coordination between the Cloud IOP and ARESE II and the ER2. Coordination with the ER2 is especially critical given the complexity of the flight planning process. Daily communication between the ER2 and the Cloud IOP will be required and should take place as early as necessary in the morning (~4:30 AM) to plan for a mission in time to coordinate with a 10:30 am Terra overpass. Interaction between the ER2 and the cloud IOP will also be required in the afternoon in order to plan for any missions that may take place the following day. Close coordination between the Cloud IOP and ARESE II is no less important but, due to proximity, coordination will be much easier.

- Daily Meetings

Successful implementation of this IOP will require careful coordination between all involved. As in the Fall 97 IOP, the Citation will be based at the Ponca City airport and the Twin Otter at the Blackwell Tonkawa airport. ARESEII will hold planning meetings at the Blackwell Tonkawa airport, and the Cloud IOP will hold planning meetings at the Ponca City airport. This physical separation is more of a concern for the present deployment because the Twin Otter is an integral component of the cloud IOP, and close coordination between ARESEII and the Cloud IOP is anticipated. However, given the limited cloud conditions under which ARESEII will operate, it should be reasonably clear what collaboration will be attempted between the Cloud IOP and ARESEII on any given day. Every effort will be made to coordinate planning between ARESEII and the Cloud IOP via conference call and /or video conferencing.

Daily morning planning meetings of the cloud IOP will be held at 6:30 AM at the Greenwood Aviation Facility at the Ponca City Airport. The early hour of the morning meeting is necessary due to the need to accommodate the complex planning that any coordination with the Terra satellite (10:30 am overpass) and the ER2 will require. The timing will also allow individuals involved in both ARESEII and the Cloud IOP's the opportunity to attend planning meetings at both facilities. The morning Cloud IOP planning meetings will proceed along the following basic agenda:

- A weather briefing and forecast discussion
- A report from the instrument PI's on the status of their instruments and availability for operations
- A report from the experiment PI's regarding the operational availability of off-site resources (Lear and ER2) and the satellite overpass schedule for that day
- Decision regarding the type and timing of any missions for that day
- Discussion and tentative planning for any mission the following day.

Evening meetings will generally be held at the Greenwood aviation facility following the completion of any coordinated data collection period. Unless otherwise notified, these meetings will be held at 5:00Pm. Attendance by instrument PI's is requested so that brief reports regarding the status of the day's data can be given. Attendance by any appropriate flight crew members is also requested.
Evening meetings will not generally be held on days when no coordinated data collection period was attempted although the Experiment PI will coordinate with off-site resources for any potential activity that might occur on the following day.

Modifications to these plans will be posted on the internet and in the major hotels.

- Data Collection and Data Propagation

Since the supplemental facilities (SF's) are not long-term SGP installations, protocols need to be established to ensure that all instruments are operating nominally during missions and that the data collected by the instruments are routinely archived with sufficient redundancy. An understanding should be reached between the individuals that are responsible for instruments (Tables 2 and 3) and data streams at the supplemental facilities and the individuals who will physically be located at the SF's to operate instruments. The on-site individuals will be responsible for the following tasks on a daily basis,

1. Setting of all critical computer clocks to some standard to be determined
2. Cleaning of radiometer domes
3. Monitoring of instrument health
4. Archival of data following a mission
5. Ensuring that all equipment is stowed properly following data collection.

A logbook will be provided to the supplemental facilities. All significant events should be carefully noted in them by the on-site personnel. Given the unusual and complex nature of this IOP, such documentation may prove crucial.

6. References

Dong, X., T. P. Ackerman, and E. E. Clothiaux, 1998: Parameterizations of the microphysical and shortwave radiative properties of boundary layer stratus from ground-based measurements. *Journ. Geophys. Res.,* **103,** 31681-31693.

Heymsfield, A. J. and A. G. Palmer, 1986: Relationships for deriving thunderstorm anvil ice mass for CCOPE storm water budget estimates. *J. Clim. Appl. Meteor.,* **25,** 691-702.

Krueger, S. K., G. T. McLean, and Q. Fu, 1995: Numerical simulation of the stratus-to-cumulus transition in the subtropical marine boundary layer. Part I: Boundary-layer structure, *J. Atmos. Sci.,* **52,** 2839-2850.

Mace, G. G., T. P. Ackerman, P. Minnis, D. F. Young, 1998: Cirrus layer microphysical properties derived from surface-based millimeter radar and infrared interferometer data. *J. Geophys. Res.,* **103,** 23207-23216.

Matrosov, S. Y., B. W. Orr, R. A. Kropfli, and J. B. Snider, 1994: Retrieval of vertical profiles of cirrus cloud microphysical paramters from Doppler radar and infrared radiometer measurements. *J. Appl. Meteor.*, **33,** 617-626.

Plank, V. G., R. O. Berthel, A. Barnes Jr., 1980: Improved method for obtaining the water content values of ice hydrometeors from aircraft and radar data. *J. Applied Meteor.,* **19,** 1293-1299.

Randall, D. A., K-M. Xu, R. J. C. Somerville, S. Iacobellis, 1996: Single-column models and cloud ensemble models as links between observations and climate models. *J. Climate*, **9,** 1683-1697.

Sassen, K., G. G. Mace, Z. Wang, M. R. Poellot, S. M. Sekelsky, R. E. Mcintosh, 1999: Continental stratus clouds: A case study using coordinated remote sensing and aircraft measurements. *J. Atmos. Sci.,* **56,** 2345-2358.

Starr, D. O'C., and S. K. Cox, 1985. Cirrus clouds, Pt. 1, Cirrus cloud model. *J. Atmos. Sci.*, **42,** 2663-2681

Stokes, G. M., and S. E. Schwartz, 1994: The Atmospheric Radiation Measurement (ARM) Program: programmatic background and design of the cloud and radiation test bed. *Bull. Ameri. Meteorol. Soc.,* **75,** 1201-1221.

Stratton, R. A., 1999: A high resolution AMIP integration using the Hadley Centre model HadAM2b. *Climate Dynamics,* **15,** 9-28.